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GLOBAL AVHRR PRODUCTS FOR LAND CLIMATE STUDIES

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ABSTRACT

Climate studies require long-term sets of geographically referenced global land surface data to initialize and validate numerical models for analysis of complex interactions and feedbacks within the earth system /1/. Conventional ground observations cannot provide all the required information and must be supplemented from satellites. Another application of long term global time series of satellite data is establishing the climatologies of both the top-of-the-atmosphere (TOA) radiances and derived surface characteristics which could in turn be used as a baseline for monitoring the climate scale variability. The AVHRR on board NOAA polar orbiters is the main source of operational global information over land, and this paper gives an overview of the basic concepts in its processing. The necessary steps are explained, and a generic scheme and a nomenclature for data products is proposed. In designing that structure, we have been inspired by the data flow in ISCCP /2/. We describe the present status of the data products available from the NOAA Global Vegetation Index (GVI) dataset /3,4/, its remaining uncertainties, and potential enhancements using e.g. Pathfinder AVHRR over land (PAL) /5,6/ dataset.

FOUR-LEVEL STRUCTURE OF AVHRR DATA PROCESSING

Four main levels of AVHRR data can be listed: A) acquisition and pre-processing of the original AVHRR readings (not addressed here); B) a set of steps for appropriate quality assurance and conversion to geophysical parameters; C) analyzed fields prepared from level B data, and D) statistics of C-data. The B-level processing is mostly remote-sensing oriented. It provides for testing and development of the methods to improve the quality of data. As such, it uses auxiliary information: observation-illumination geometry, calibration coefficients, quality/cloud (QC) flags. The remote sensing scientist can use different techniques to get through each step. In contrast, the C-level data are for the users who need these products for initialization and validation of the models and do not want to spend time and resources on processing the remotely sensed data.

<u>The B level</u> processing is shown schematically in Fig.1. The AVHRR orbits, pre-processed at the A-level, are supplied by NOAA with appended (not applied) information on navigation and calibration and are usually referred to as 1B-level data (B1 in our notation). The data mapped daily into a regular geographical grid are denoted as B2. Often, composites are derived by temporal sampling, e.g. keeping the pixel corresponding to the "clearest" day of the compositing period. The composite maps are referred to as B3. Thus, the input to the B-level processing are BX.0 data: B1.0 (orbits), B2.0 (daily maps), B3.0 (composite maps), with any of them being a possible starting point for further processing. The first step -- calibration -- involves conversion of sensor counts to physical quantities. The calibration coefficients are applied to the counts so that the BX.1 product contains TOA bidirectional reflectances, ρ, in solar channels and brightness temperatures, T, in thermal IR. At the next step, QC control is applied to each pixel, with results packed in N-bit flags. The QC flags are appended but not applied, with flexibility retained for some specific applications by the users. The QC maps are appended to BX.1 making it the BX.2 data products. Atmospheric and surface anisotropy and diurnal variability corrections (normalization to common observation-illumination geometry and common local solar time) are made at the next two steps, BX.3 and BX.4, respectively. Conversion to geophysical parameters is done at the BX.5-step on a pixel-by-pixel basis (including cloud contaminated ones which will be further excluded on C-level).

The C-level uses the B-data as input (Fig.2). The QC flags are applied, and the resulting data gaps are filled in by spatial/temporal averaging/interpolation. Residual noise in data due to imperfections in both the original data and in the B-level processing, is partially filtered out by spatial/temporal smoothing. All auxiliary information is omitted, and complete fields of climate variables are produced. Ideally, the B2.5 (the mapped daily data of geophysical parameters with appended QC flags) is the preferable input to the C-level. Since this is not always achievable, we use a flexible nomenclature for the C-products: CX.Y/TS, with X=1,2,3 and Y=1,2,3,4,5, denoting that the C-product was derived from BX.Y data, and TS standing for temporal and spatial resolution (see Fig. 2). Obviously, the quality of C-level products depends upon the success of the B-level processing, as well as averaging/interpolation/smoothing schemes used at the C-level.

The D-level uses the C-data to derive statistics. This is the final level of data and is most useful for climate analysis.

THE PRESENT STATUS OF GVI DATA PRODUCTS

The NOAA GVI products routinely available at NOAA/NESDIS are B2.0 (daily mapped data) and B3.0 (weekly composites, the clearest day of the week corresponds to max(Ch2-Ch1), although only the latter is well advertised, used by the scientific community and actually known as the operational NOAA GVI product. Both B2.0 and B3.0 are given on $(0.15°)^2$ lat/lon grid and comprise raw counts in AVHRR Channels 1, 2, and "GOES" counts in 4, 5, NDVI, solar zenith angle, Θ_s, and scan angle, Θ_v. The presently available data products based on B3.0 are: B3.1 (calibrated composites), B3.2 (QC-flags appended); C3.2/M15 (monthly fields), and D3.2/M15 (a 5-year monthly climatology), all with the $(0.15°)^2$ resolution for the whole observational period of the second generation GVI (Apr 1985 -present).

The B-level GVI products (B3.1 and B3.2). The solar channels, not calibrated in flight, are known to degrade with time /7/. The bidirectional reflectances in solar channels $\rho=\pi \cdot L \cdot W \cdot F_s^{-1} \cdot \mu_s^{-1}$ ($\mu_s=\cos\Theta_s$; F_s and W are the TOA solar flux and effective width for a given channel) are calculated from the radiances L, $W \cdot m^{-2} \cdot \mu m^{-1} \cdot sr^{-1}$, derived using the updated (Pathfinder) calibration /7/ and include the Sun-Earth distance correction. Brightness temperatures T_4 and T_5 are calculated using the on-board calibration, taking into account the non-linearity correction /8/. The $NDVI=\{(\rho_2-\rho_1)/(\rho_2-\rho_1)\}$ is recalculated, and $\Delta T=T_4-T_5$ calculated at the B3.1 level, to retain accuracy, since all B3 values are packed into 8 bits.

The composite imagery is cloud contaminated in many parts of the world /9/; thus additional screening is mandatory. Cloud screening in composite imagery over land is not a trivial task since the adjacent pixels can be from different days of the compositing period with quite different Sun-view geometry and weather conditions. We have developed a special procedure for cloud screening in composite imagery based on thresholding T_4 /9/. Thirty-six global monthly threshold maps with (2°) spatial resolution were developed for 12 months and three 30°-viewing angle bins.These thresholds are applied to each weekly composite to generate the QC flags. Together with updated calibration, the generation of QC flags is the major enhancement in the GVI dataset. If the better QC flags are developed, they will replace the present ones. The B3.2 output consists of weekly composite maps of TOA ρ_1, ρ_2, NDVI, T_4, T_5, ΔT, Θ_s, Θ_v, and QC flags. The current weekly composites are being processed routinely and appended to the existing time series.

The C-level GVI product (C3.2/M15). Application of the QC masks to weekly composites results in images with blank areas. We generate the C-products on a monthly basis, in order to partially fill in the blank areas and to reduce the noise in ρ and T, resulting from uncorrected angular and atmospheric variability. Monthly averaged images, however, still contain blank areas because of persistent cloudiness during the whole month in some seasons/regions. Those are filled in by bi-linear interpolation in space (the present monthly processing precludes using interpolation in time). A 3x3 map cell smoothing is done to partially account for the imperfection of the original B3.0 data and the B-level processing, as well as the lack of steps B3.3-B3.5. The above procedure yields a monthly mean values for the TOA ρ and T, NDVI and ΔT at each GVI map cell for each month of each year of the observational period. Note that in order to proceed with derivation of the surface characteristics, it is necessary to first generate B3.3-B3.5.

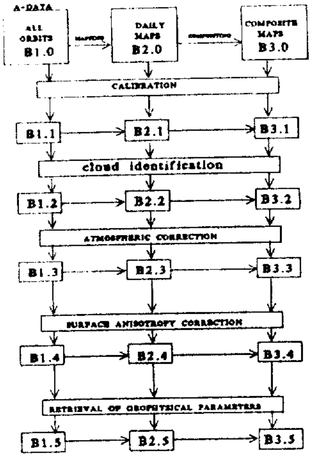

Fig.1. The B-level processing.

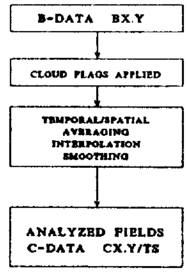

Fig.2. The C-level processing. T=D,W,Dc,M,S,Y for daily, weekly, 10-days, monthly, seasonally and yearly. S can be 8, 15, etc. for 8-km (≈0.08°) PAL and 0.15° GVI resolutions.

The D-level GVI product (D3.2/M15): 5-year AVHRR TOA "climatology". Multiannual means and variances have been calculated from the C3.2/M15 data. This allows the time series of standardized anomalies to be calculated and analyzed. Only 5 years were used to generate a reference mean state and variances: 1985-87 (NOAA-9) and 1989-91 (NOAA-11). These years correspond to early equator crossing time and the pre-Pinatubo period. Mt.Pinatubo eruption in June 1991 had strong impact on observed radiances. This 5-year "climatology" of ρ_1, ρ_2, NDVI, T_4, T_5, and ΔT has been developed for each $(0.15°)^2$ map cell of the global land surface yielding the D3.2/M15 data product. The number of years used for averaging, stored as an additional map, is useful for identifying areas with persistent cloudiness.

REMAINING UNCERTAINTIES AND POTENTIAL ENHANCEMENT OF GVI

All levels of processing are incomplete and have deficiencies. The calibration and cloud screening techniques have potential for improvement. The B3.3-B3.5 products are yet to be generated. On the C-level, the use of optimal averaging and interpolation is preferable to fill in the blank areas. These, however, require the spatial/temporal correlation functions, which are not available now. The D-level can also be improved by considering longer time series and developing other statistical parameters.

Atmospheric and surface anisotropy effects. The major distortion of the signal in solar channels by the atmosphere is due to aerosol and water vapor. Neither accurate global observations nor climatologies of these constituents are presently available. Recent pilot studies indicate potential to correct the effect of Mt. Pinatubo in solar channels /10/. Tests with the GVI B3.2 data for the period 1991-93 are underway. Atmospheric correction in thermal IR can be done by a split-window procedure, which does not require detailed information about total amount/vertical distribution of water vapor. Application of the split-window technique for land surface temperature retrieval is challenging because of variable emissivity. Several studies have shown that much of the contribution to angular variability in the observed radiances is due to surface anisotropy /11/. Thus, even if the atmospheric corrections are made, it is unclear how the results could be interpreted. A single globally applicable correction is not possible due to variability of surface effects in space and time. Models for specific vegetation types are also not a panacea because of landscape variability.

An alternative approach. Since atmospheric and angular correction of GVI data is presently infeasible, an alternative approach was proposed in /12/. It is based on developing regional TOA empirical angular functions (REAF). The REAF's are utilized to normalize all data to a common sun-target-sensor geometry. This should be done over the global land surface. The number of the REAFs can be reduced later using cluster analysis. Pilot studies indicate that the time series become more stable after TOA normalization. The effective elimination of angular biases allows more reliable interpretation of the results and widens the area of applicability for analysis. The methodology has yet to be improved and tested further before it is applied globally.

CONCLUSION

A generic nomenclature and processing structure of global AVHRR data are proposed. Enhanced GVI climate products and their remaining uncertainties and potential enhancements are described. In many aspects GVI resembles the newly formed PAL /6/. Both are long-term multi-spectral multi-satellite globally-uniform AVHRR data sets; both present a subsample of the GAC data mapped into regular grids, with each map cell being represented by a single GAC 4km-pixel. The GVI dataset has been criticized (e.g. /13/) because some irreversible damage has been done in the process of its collection. Despite the deficiencies, the GVI, as the first long term uniformly mapped AVHRR land dataset, has been widely used for large scale land surface studies, and allowed knowledge on the complexity associated with the sensor and satellite drifts to be accumulated. The PAL dataset, however, will provide enhanced statistics, better quality and more information as compared to GVI, because of its higher spatial and radiometric resolutions, longer time series, better sampling and availability of daily cloud flags.

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